TanDEM-X Bistatic SAR Processing

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Abstract

In June, 2010 the German SAR satellite TanDEM-X (TerraSAR-X-Add-on for Digital Elevation Measurements) will be launched. Together with TerraSAR-X, launched June 15, 2007, it will form the first spaceborne bistatic SAR platform. Usually one of the satellite is transmitting (active satellite), while both are receiving. As both satellites fly in a helix orbit constellation, during a recording a satellite has to be passive, if the other one is close to the line of sight to the observation target at the moment of observation in order not to destroy the instruments of the other satellite, in other words they change their roles along the orbit. Even tiny differences in the instruments of both satellites can yield huge effects on final products. Within this paper we present the approaches of correcting thus differences.
In the first part we explain, what variances in the satellite hardware are expected and how they are determined. In the second part we show, how the SAR processing copes with those differences.

1 Hardware Differences

Differences between TerraSAR-X and TanDEM-X hardware, even though intending to build an identical second satellite, might come just from slight variation in hardware production. Athough very small they might have strong impacts on the final bistatic SAR product. Thus they have to be examined in detail and corrected as far as possible. Without having access to an absolute time reference, we use the active satellite as reference and evaluate the timing of the passive satellite relative to it. In so doing, all corrections which relate to timing are applied on the imaging channel of the passive satellite.

Variations in the antenna hardware yield to different antenna patterns in both signal gain and phaseshift. For the interferogram, a fully corrected image phase is needed. Thus according to the well known antenna pattern of a certain imaging mode and look angle, the phase pattern is projected to the ground range area of the scene according to timing, orbit, attitude and coarse (input) DEM information. This projected phase antenna patterns are sampled on a ground grid for further usage within the processing chain. The projection is already included in the newest version of the TerraSAR multimode SAR processor (TMSP) [3].

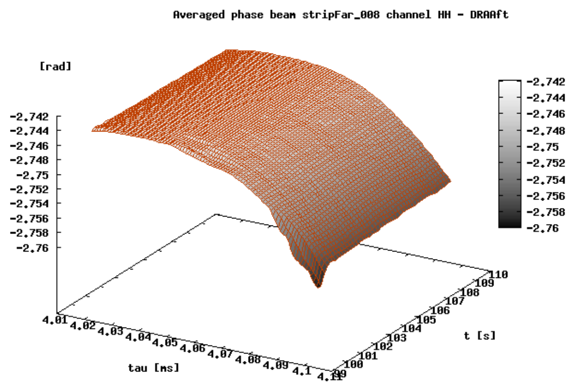

Figure 1: Phase antenna pattern of a TerraSAR-X scene

Figure 1 shows an exemplary phase antenna pattern for HH polarization[1] of a Quadpol TerraSAR-X scene in stripmap beam "stripFar_008" recorded on April 24, 2009 in southern Bavaria, Germany in ascending orbit direction. One can easily see the effects of the mountains (Alps) at the early azimuth (front part) of the plot.

Besides the antenna hardware another electronic part has impact on the image phase. The ultra stable oscillators used for all signal generation and timing of the satellites might slightly differ in frequency due to unavoidable manufacturing tolerances. These differences might even vary or drift within a datatake. Thus several effects might occur:

[1]this polarization is recorded on the antenna half at the backside of the satellite according to flight direction

- On long term the pulse timing and thus echo window positions (EWPs) of the two satellites might drift apart during a datatake.
- On smaller scale the signal phase might slightly drift apart.

A sophisticated synchronization strategy is used to determine the frequency differences and phase drifts. At certain events both satellites exchange synchronization pulse signals in order to get information needed to derive the amount of the drift.
Synchonization pulses are chirps sent from one satellite to the other. They occur at high pulse repetition frequency (PRF) before and after a datatake to derive a fast drift behaviour. Several thousand pulses are sent in alternating direction. During the datatake around 10 times (so called low synchronization PRF) a second pulse is sent in each direction to correct for fine variations of the drift (for details cf. [1]).

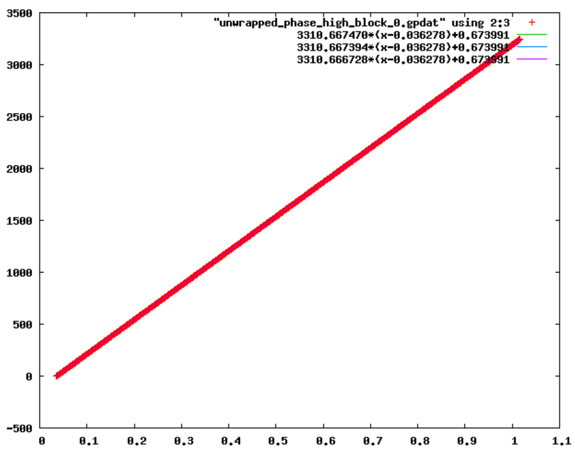

Figure 2: Measured unwrapped phase drift from synchonization pulse simulation of a constant 18 Hz oscillator difference

Figure 2 shows a plot of the measured unwrapped phase drift from the synchonization pulses of the datatake start high PRF block of a datatake with a simulation of a constant 18 Hz oscillator difference without any orbit effects included.
So called leap PRIs (PRI=pulse repetition imterval) are introduced to one of the image timelines, according to the value of the general drift known from the commisioning phase which is carried out in mid 2010. This means that the PRI of a single imaging pulse cycle of the passive satellite is slightly changed in order to get the timing of both satellites close to simultanous again.
The whole drift analysis is also done in an image quality precheck sceneario before the whole image data which are received around the world are shipped to DLR Oberpfaffenhofen. This allows to record a scene anew in the same orbit configuration when corrupted synchonization signals or unexpected drifts occur.

2 Corrections in Processing

Frequencies and timings which are derived from the oscillator frequency are as well different between the satellites. This refers to e.g. the pulse repetition frequency (PRF) and the range sampling frequency (RSF). But the difference in the oscillator frequency has also an impact on the phase of the demodulated raw data signal.

One might expect that the different timing necessitated a resampling of the focused image of the passive channel in azimuth and range. But with the sequence of transmitted radar pulses, the active satellite provides the azimuth timing for both, the active and the passive imaging channel. As **Figure 3** illustrates, the pulse cycle start times of the receiving satellite just have an effect on the position of the echo data window in the respective cycle. But the echo window position refers to range direction. Thus, the different start time of a pulse cycle in both channels can be considered by a range shift of the echo window in the passive channel. Hence no resampling in azimuth is necessary. In each pulse cycle, the amount of the range shift is equal to the delay of the pulse cycle start time of the passive satellite relative to the corresponding pulse cycle start time of the active satellite.

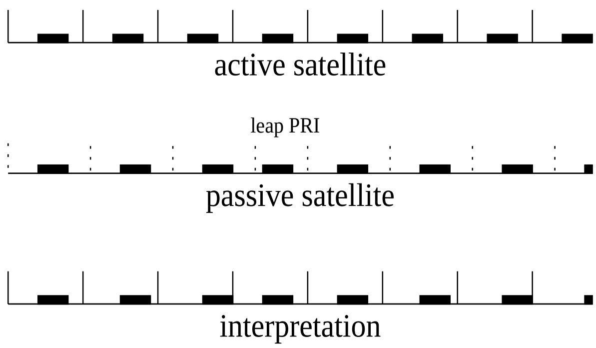

Figure 3: Timelines of active and passive satellite and the interpretation of the timeline of the passive satellite in processing. In each sketch, time t_{abs} runs from left to right. Vertical lines represent the transmit pulse positions, filled boxes the window positions for echo data receive. Because the passive satellite does not transmit radar pulses, its "transmit pulse positions" constitute only timetags (doted lines), the EWP refers to. In the middle of this sketch, there is a leap PRI. During processing, the EWP of the passive satellite are considered relative to the transmit pulse positions of the active satellite. Hence the azimuth timing of both satellites is equal while the EWP of the passive satellite varies from pulse cycle to pulse cycle.

For the evaluation of the effect of the oscillator frequency variation on the phase of the demodulated raw data signal, we refer to the radar equation. The radar pulse response of a single point target is

$$d(\tau) = a_\Theta(\Theta) a_\beta(\beta) g\left(\tau - \frac{2R}{c}\right) e^{2\pi i \nu_0 \left(\tau - \frac{2R}{c}\right)} \quad (1)$$

where $a_\Theta(\Theta)$ and $a_\beta(\beta)$ are the amplitude two-way antenna patterns in elevation and azimuth, respectively, $g(\tau)$ is the complex envelope of the transmitted radar pulse, R the distance between satellite and target, c is the light velocity and ν_0 the carrier frequency. By demodulation, the carrier frequency is removed from the phase term $2\pi i \nu_0 \cdot \left(\tau - \frac{2R}{c}\right)$. In the case of a monostatic SAR system, radar pulse response and demodulator refer to the same carrier frequency and

$$\begin{aligned} \varphi &= 2\pi i \nu_0 \cdot \left(\tau - \frac{2R}{c}\right) - 2\pi i \nu_0 \tau \\ &= -2\pi i \nu_0 \cdot \frac{2R}{c} = -4\pi i \cdot \frac{R}{\lambda} \end{aligned} \quad (2)$$

gives the phase of the demodulated raw data signal [2]. Hence, there is just a constant phase shift which is due to signal propagation delay. In the case of the bistatic constellation, the same is true for the active satellite. In contrary, the passive satellite uses a slightly different carrier frequency $\tilde{\nu}_0$ for demodulation and here

$$\begin{aligned} \varphi &= 2\pi i \nu_0 \cdot \left(\tau - \frac{R_{\mathrm{Tx}} + R_{\mathrm{Rx}}}{c}\right) - 2\pi i \tilde{\nu}_0 \tau \\ &= 2\pi i \cdot (\nu_0 - \tilde{\nu}_0) \cdot \tau - 2\pi i \cdot \frac{R_{\mathrm{Tx}} + R_{\mathrm{Rx}}}{\lambda} \end{aligned} \quad (3)$$

is the phase of the demodulated raw data signal. R_{Tx} and R_{Rx} denote the distance of transmitting and receiving satellite to the target, respectively. We introduce this distinction which is relevant for subsequent interferometric processing, just for the sake of accuracy. Relevant for the subject matter is the additional beat term $2\pi i \cdot (\nu_0 - \tilde{\nu}_0) \cdot \tau$. It results from the difference in carrier frequency and has to be compensated in processing. Note that both oscillators carry on running from pulse cycle to pulse cycle. Thus, fast time τ has to be substituted by the absolute time t_{abs}. In contrast to the common usage in SAR community, for the purpose in view it is not convenient to subdivide the absolute time t_{abs} in slow time t which is incremented pulse by pulse and fast time τ which is reset with each pulse.

3 Outlook

By the end of the commissioning phase precise variation ammounts and error budgets of the various hardware differences can be given. This will include frequency offsets, drifts and examples of imaging errors when turning off one of the corrections.

References

[1] *TanDEM-X System Engineering and Calibration*, issue 1.3, Oberpfaffenhofen: German Aerospace Center (DLR), Microwave and Radar Institute, Aug. 2009

[2] Richard Bamler and Birgit Schättler: *SAR Data Acquisition and Image Formation*, in *Geocoding: ERS-1 SAR Data and Systems*, Wichmann-Verlag, 1993, pp. 53–102

[3] Helko Breit and Thomas Fritz and Ulrich Balss and Marie Lachaise and Andreas Niedermeier and Martin Vonavka: *TerraSAR-X SAR Processing and Products*, in *IEEE Trans. Geosci. Remote Sens.*, Vol. 48, No. 2, Feb. 2010, pp. 727–740